

## CONTROL OF THE TEMPORAL LOCATION OF POLYDIPSIC LICKING IN THE RAT

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We studied the variables controlling the temporal location of polydipsic licking. Four rats were trained on a mixed fixed-ratio 10 (no tone) chained fixed-ratio 10 (no tone) fixed-ratio 90 (tone) schedule and on a multiple fixed-ratio 10 (tone) fixed ratio 100 (no tone) schedule. On the multiple schedule, drinking followed pellets if a fixed ratio 100 was upcoming for all four subjects and for two of the subjects if a fixed ratio 10 was upcoming. On the mixed schedule, drinking preceded the fixed-ratio 90 component of the chain. Two subjects also drank after pellet delivery on the mixed schedule before both the fixed ratio 10 and the chain components. The number of licks was greater following a pellet than following a response. In a second phase with two of these subjects, the total response requirement of the chain was held constant at 100, while the size of the two ratios that constituted the chain was varied inversely. The tone signaled onset of the second link. Drinking followed the tone when it signaled fixed-ratio 90, 95, or 100 but not when it signaled fixed ratio 75, 80, or 85. These results show, on the one hand, that polydipsic licking is controlled by discriminative properties of the pellet rather than by its eliciting or "thirst-producing" characteristics. On the other hand, the fact that drinks were longer following a pellet than following a response suggests a contribution of thirst to polydipsia.

*Key words:* polydipsia, lick location, mixed schedules, fixed ratios, rats

Since Falk (1961) discovered that the intermittent delivery of food produced excessive drinking in rats, considerable interest has focused on this phenomenon (Falk, 1971; Staddon, 1977). An important feature of polydipsia is the postpellet location of the drinking. This postpellet licking has led to the suggestion that eating dry pellets produces "thirst" due to a dry mouth (Stein, 1964). But Flory and O'Boyle (1972) and Gilbert (1974) showed that rats will drink during time periods other than after pellet delivery if the availability of the drinking tube is temporally restricted. Others have shown that drinking is not restricted to the postpellet period when the drinking tube is freely available. For example, on schedules where responses are reinforced only if the time

since the last response is greater than a minimum value, drinking sometimes follows unreinforced responses (Segal & Holloway, 1963; Smith & Clark, 1974). On second-order schedules, drinking follows brief stimuli when these both do and do not accompany pellet delivery (Corfield-Sumner, Blackman, & Stainer, 1977; Porter & Kenshalo, 1974; Rosenblith, 1970).

An alternative account based on discriminative properties of the food pellet has been suggested. According to this account, drinking occurs during times when the probability of pellet delivery is low (Falk, 1969; Staddon & Simmelhag, 1971). This view is supported by the fact that licking is confined to extinction periods on both mixed fixed-ratio (FR) 1 Extinction (Keehn & Colotla, 1970) and multiple FR 1 Extinction (Keehn & Colotla, 1971) schedules where a series of FR 1 components alternated with a period of extinction. Drinking did not occur between pellet deliveries during the FR 1 component but followed the last pellet delivery at the beginning of the Extinction component. Stone, Lyon, and Anger (1978) found that less licking occurred in the last 5 sec of a 15-sec postpellet period if a tone preceded a pellet than if this tone and

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pellet were omitted. Millenson, Allen, and Pinker (1977) found that even subtle differences in the probability of food delivery affect polydipsic drinking. Polydipsia did not develop readily on random variable-interval schedules but did on arithmetic variable-interval schedules.

To separate drinking controlled by the discriminative properties of the food pellet from drinking controlled by the eliciting or "thirst-inducing" properties of the pellet requires the following characteristics: (a) control of drinking by an arbitrary stimulus, (b) whose onset should not immediately precede or follow pellet delivery, and (c) which signals a low probability of food. A mixed FR schedule meets these requirements. Pausing on these schedules commonly occurs in the larger ratio following completion of approximately the number of responses required by the smaller ratio (Alferink & Crossman, 1975; Ferster & Skinner, 1957). If a stimulus change occurs at this point (as in a chain FR FR), the stimulus change controls the location of the pause (Alferink & Crossman, 1976). The purpose of this study was to determine if this stimulus change would control drinking even when the stimulus neither immediately preceded nor immediately followed pellet delivery.

## METHOD

### *Subjects*

Four experimentally naive male Long-Evans rats were maintained at approximately 80% of their ad lib weight (372 to 520 g). Each animal was individually housed with water continuously available from a calibrated glass tube mounted on the side of the home cage. Subjects were given supplemental feedings of Purina Lab Chow in the home cage following sessions if needed.

### *Apparatus*

A standard operant chamber was used, measuring 39.5 cm by 35 cm by 33 cm and enclosed in a sound-attenuating shell. A Davis pellet dispenser delivered 45-mg Noyes pellets into a food cup mounted in the center of one wall. A lever was mounted 5 cm to the left of the food cup and a glass drinking tube 5 cm to the right of the food cup so that the subject could not drink and lever press at the same time. A white Plexiglas disk in the wall above

the lever could be transilluminated during sessions.

The chamber was illuminated by a 7.5-W bulb. Masking noise was provided by a ventilating fan mounted on the sound-attenuating shell and by a speaker mounted within the shell. This speaker was also used for presenting a tone as described below. All programming and recording were accomplished with solid-state logic (BRS-LVE), a cumulative recorder, and a three-channel printout counter. A solid-state drinkometer (BRS-LVE) recorded licking.

### *Procedure*

*Phase 1.* After each subject was reduced to 80% of free-feeding weight, a baseline of water consumed in the home cage during each 24-hour period was obtained. This baseline remained in effect for a minimum of eight days. Then lever pressing was shaped and the response requirement was gradually increased until stable responding on an FR 100 schedule was established. The glass drinking tube was not present.

Following this training, a *chain* FR 10 FR 90 schedule alternated randomly with an FR 10 schedule. The stimulus conditions present after pellet delivery were the same for both the *chain* FR 10 FR 90 and the simple FR 10, making this a *mix* FR 10 *chain* FR 10 FR 90 schedule. Each session began with the chain. Completion of ten responses produced a tone which remained on until the emission of 90 additional responses and pellet delivery and then went off. Thus, the tone was strictly correlated with the FR 90. Each pellet delivery was accompanied by a .5-sec illumination of the disk above the lever. During the light, responses had no programmed consequences to prevent extra lever presses before ingestion of the pellet from interfering with data recording. Following each pellet, the probability of the *chain* FR 10 FR 90 schedule was .75, and the probability of the simple FR 10 was .25. These probabilities were randomly generated.

For one rat (R-1), the glass drinking tube was inserted into the chamber with the introduction of this mixed schedule. For the remaining rats, the drinking tube was introduced following the development of stable pausing after the onset of the tone in the chained component of the mixed schedule. This was done because data from a separate study suggested that if polydipsia developed

before the tone controlled pausing, the tone would exert less control over drinking. Data for R-1 had been obtained before this data was available.

After the location of licking and the amount of water consumed during each session on the mixed schedule had stabilized, a *mult* FR 10 FR 100 schedule was introduced. Each session began with the FR 100 where 100 lever presses produced a pellet and the .5 sec light. The FR 100 occurred with a random probability of .75 with the FR 10 component occurring with a probability of .25. On the multiple schedule, the tone was perfectly correlated with FR 10. Following stability on this schedule, an attempt was made to recover responding on the mixed schedule and subsequently on the multiple schedule.

Following this, each subject was placed in the experimental chamber for three hours each day. The mean number of food pellets obtained during the last eight sessions was placed in the food cup at the beginning of each experimental session. The lever was removed from the chamber, and no additional pellets were delivered. The rats were removed after three hours, the duration of an experimental session. This control condition was delayed until after Phase 2 (see below) for rat R-1.

*Phase 2.* In a second phase of the experiment, the location of the tone was varied in the chain component of the mixed schedule. The purpose was to assess whether the control of licking by the tone resulted from the fact that the response requirement was the same in the simple FR 10 and in the FR 10 component of the chain or from the fact the tone signaled onset of the larger ratio component of the chain. Only two rats (R-1 and R-2) were used in Phase 2. These two rats had showed little or no postpellet drinking during the mixed schedule in Phase 1 and, therefore, the greatest control by the tone.

Initially, the tone came on following the 5th lever press (*chain* FR 5 FR 95). Subsequently, the tone came on following the 10th (*chain* FR 10 FR 90), 15th (*chain* FR 15 FR 85), 20th (*chain* FR 20 FR 80), and (for R-1 the 25th (*chain* FR 25 FR 75) response of the chain. Recovery points were obtained for *chain* FR 15 FR 85 and *chain* FR 10 FR 90. The total response requirement of the chain was held constant at 100 responses while the response requirement of the simple component

of the mixed schedule was held constant at 10 responses. A subsequent condition reinstated the *mult* FR 10 FR 100 schedule with the stimuli reversed. Thus, tone was strictly correlated with FR 100 and no tone with FR 10. Following this, rat R-2 was exposed to a *chain* FR 10 FR 90 schedule; simple FR 10 no longer occurred. The purpose was to determine whether the tone would continue to control drinking when the simple FR 10 was not present.

Each daily session lasted three hours. Water consumed was measured immediately following the session and was corrected for evaporation and spillage. Each condition was in effect for at least 10 sessions and until no trend was present in the location of licking for the last eight sessions.

## RESULTS

Four rats developed polydipsia. The mean daily water consumed in 24 hours in the home cage during the last eight days before water was made available in the experimental chamber is shown in Table 1. When water was introduced in the experimental chamber during the mixed schedule, water consumed (in 21 hours) in the home cage decreased for all rats relative to baseline. For rats R-3 and R-4, total mean water consumed in the home cage and the chamber for the last eight days on the mixed schedule was greater than baseline. This was generally true of all subsequent conditions. For R-1, water intake did not increase until exposure to the multiple schedule with polydipsia developing during the reintroduction of the mixed schedule. R-2 did not develop polydipsia until the reintroduction of the mixed schedule. In the control condition, rats were fed the mean number of pellets obtained during the last eight sessions at the beginning of each experimental session. The water consumed in the experimental chamber during these control sessions decreased relative to the preceding multiple schedule.

The locations at which subjects drank during Phase 1 are illustrated in Figure 1, which shows the frequency of lick episodes as a function of the number of responses. Drinking occurring after zero responses is commonly called "postpellet licking." A licking episode was defined as one or more licks preceded and followed by a lever press or a food pellet. At the right of each histogram is the frequency of

Table 1

Means and ranges of consumption (ml) during the last 8 days in the home cage and in the experimental chamber, and the total 24-hour water consumption for each of the 4 rats.

	R-1			R-2		
	Cage	Chamber	Total	Cage	Chamber	Total
Baseline	36.5 (32-41)	— —	36.5 (32-41)	26.9 (20-35)	— —	26.9 (20-35)
Mixed	17.6 (12-21)	17.7 (14-20)	35.3 (34-38½)	11.9 (0-22)	16.0 (2-26)	27.9 (16-34)
Multiple	20.4 (13-33)	21.5 (15-27)	41.9 (32-57)	7.7 (1-18)	13.2 (10-20)	20.9 (17-29)
Mixed	27.1 (15-40)	29.7 (22-34)	56.8 (44-74)	8.6 (4-12)	17.7 (14-22)	26.3 (24-30)
Multiple	9.7 (4-20)	43.6 (44-53)	53.3 (27-73)	18.5 (16-24)	23.7 (22-29)	42.2 (38-53)
Control	11.4* (9-14)*	17.2* (14-20)*	28.6* (23-34)*	9.1 (1-20)	11.2 (6-16)	20.3 (7-30)
	R-3			R-4		
	Cage	Chamber	Total	Cage	Chamber	Total
Baseline	24.9 (13-34)	— —	24.9 (13-34)	30.1 (24-40)	— —	30.1 (24-40)
Mixed	7.5 (2-16)	53.9 (42-70)	61.6 (48-72)	6.6 (4-12)	37.9 (30-43)	44.5 (37-50)
Multiple	3.0 (2-4)	63.9 (54-80)	66.9 (56-83)	5.4 (2-21)	50.6 (40-68)	55.0 (44-65)
Mixed	11.5 (2-38)	54.7 (36-72)	66.2 (44-94)	7.5 (1-30)	58.2 (46-74)	65.7 (51-85)
Multiple	3.6 (1-15)	67.8 (33-60)	71.4 (35-66)	6.0 (3-14)	51.2 (32-66)	57.2 (37-71)
Control	— —	— —	— —	10.2 (3-17)	11.6 (8-20)	21.8 (13-30)

\*Obtained after Phase 2.

licking episodes following pellet delivery before responding on the simple FR 10 component.

Rats R-1 and R-2 seldom licked following pellet delivery on the mixed schedule. Instead, their licking was confined almost exclusively between the 10th and 20th response of the chain, with the greatest frequency of episodes occurring after 10 or 11 responses. For R-3 and R-4, the greatest number of licking episodes in the chain followed pellet delivery, and the remainder primarily followed responses 9 through 20 yielding a secondary mode after 10 or 11 responses. R-3 and R-4 also drank after the pellet before responding on the simple FR 10 component whereas R-1 and R-2 did not drink during FR 10.

Results on the *mult* FR 10 FR 100 schedule contrast with those obtained on the mixed schedule. For all rats, nearly all of the licking

episodes on the multiple schedule occurred following pellet delivery. For R-3 and R-4, the drinking occurred before responding on both FR 10 and FR 100 while R-1 and R-2 confined their licking to the FR 100 component.

Reinstatement of the mixed schedule increased the frequency of postresponse licking episodes in the chain for all rats and decreased drinking for R-1 and R-2. Reinstating the multiple schedule restored drinking prior to initiation of responding on FR 100. Drinking on FR 10 remained as described above. That is, R-1 and R-2 did not drink during FR 10, and R-3 and R-4 licked after pellet delivery or occasionally after the first response on FR 10. Drinking at other locations during FR 10 was not observed.

Portions of selected cumulative records are shown in Figure 2 for rats R-1 and R-4. These records were selected from one of the last eight

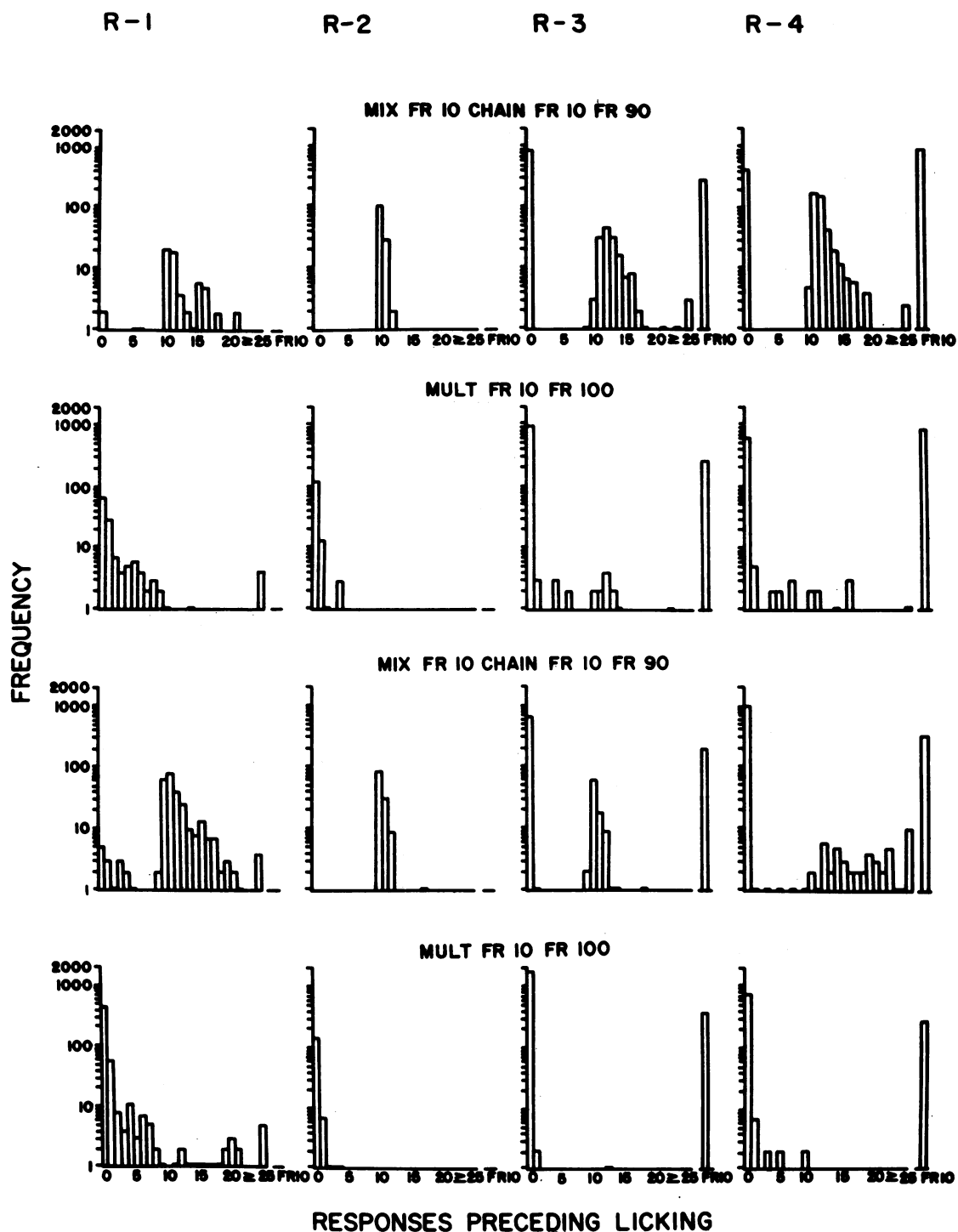


Fig. 1. Frequency of licking episodes at each location for each subject in each condition in Phase 1. Licking during the component requiring 100 responses is represented on the left; licking during FR 10 is represented in the bar on the right for each subject. Schedule conditions are represented from top to bottom in the order in which they occurred. Note the log scale on the y-axis.

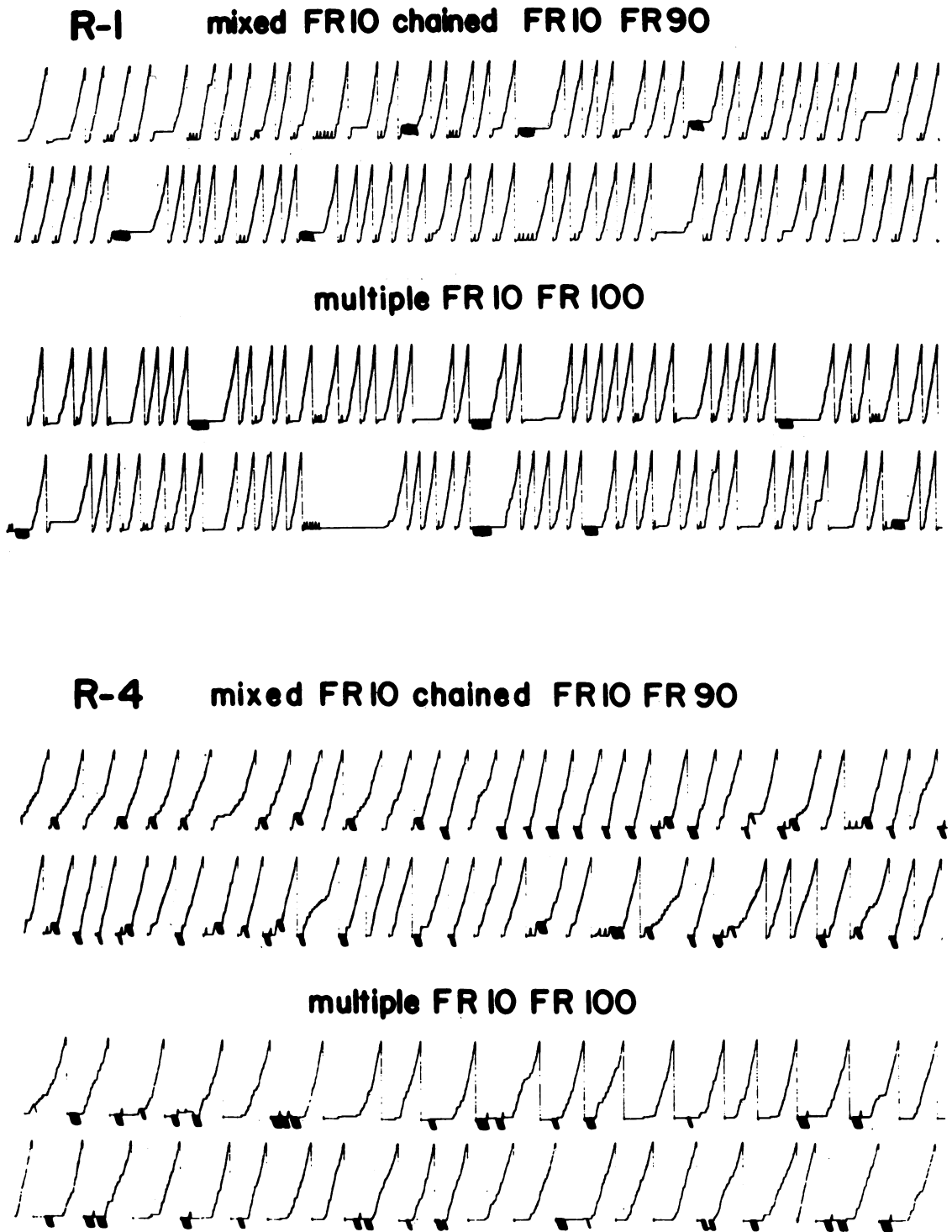


Fig. 2. Selected cumulative records for R-1 and R-4 obtained from the first exposure to the *mix* FR 10 *chain* FR 10 FR 90 and the *mult* FR 10 FR 100 schedules. The response pen reset with food delivery. Licks are represented by pips on the response record.

sessions of the first exposure to the mixed and the multiple schedules. These two rats exemplify the two different patterns of licking obtained in this study. On the one hand, Rat R-1 licked almost exclusively preceding FR 90 of the chain component of the mixed schedule. On the other hand, R-4 licked following pellet delivery before both FR 10 and the chain and preceding responding on FR 90 as well.

On the multiple schedule, both R-1 and R-4 confined their licking almost exclusively to the time between pellet delivery and the first response. R-1 licked before FR 100; R-4 licked before both FR 10 and FR 100.

Table 2 shows the mean number of licks per episode after pellet delivery or after a response. The number of responses which had occurred before licking was ignored as long as at least one response per episode preceded one or more licks. In general, more licks occurred following pellet delivery than following a response. The exceptions were rat R-1 during the second exposure to the mixed schedule wherein more licks occurred after responding than after the pellet. On those schedules where postpellet licking occurred, the same number of licks occurred postpellet and postresponse for R-2. In addition, there are three or four cases where postpellet and postresponse licking was approximately equal. For R-3 and R-4 (the two rats that drank following pellet delivery before initiating responding on the FR 10 components), postpellet licking is shown separately for the large and small components. For R-4, the number of licks following a pellet was equivalent whether the rat had emitted 10 responses or 100 responses to produce a pellet; and no systematic differences existed for R-3 in postpellet licks between these two components.

For all rats, the number of licks that occurred following a response during the large component did not vary systematically with the number of responses remaining in the ratio. The number of licks per episode following one response was not systematically different from the mean number of licks following 10 or 20 responses.

Figure 3 shows the results of Phase 2 of the experiment in which onset of the tone within the chain was varied. When the tone followed the fifth response in the chain (initiating FR 95), licking followed the fifth response and preceded responding on the FR 95. This same

correlation between the onset of the tone and licking also occurred in the *chain* FR 10 FR 90. However, this correlation between the tone and licking was weaker when the tone came on after 15, 20, or 25 responses. In these cases, licking episodes occurred after approximately 12 to 15 responses with slightly more episodes before than after the 15th response.

When responding was reinforced according to a *chain* FR 10 FR 90 schedule for rat R-2, the pattern of drinking was different from that obtained in any chain component in the previous mixed schedule. R-2 drank exclusively following pellet delivery during this condition. This is the same pattern that prevailed during the multiple schedule in that licking followed the pellet if the upcoming ratio was FR 100. This relationship was true whether tone signaled FR 10 (top left column for each rat in Figure 3) or FR 100 (top right column for each rat).

## DISCUSSION

Previous studies have often focused on the hypotheses that polydipsia is controlled by consumption of the dry pellet (Stein, 1964) or by the delivery of food pellets which signal a low probability of reinforcement (Falk, 1971). The present study separated these two variables. When rats were exposed to the multiple schedule, they showed the postpellet licking generally obtained in studies of schedule-induced polydipsia (Falk, 1971). However, when the reinforcement schedule was a *mix* FR 10 *chain* FR 10 FR 90 schedule, licking was not confined to the postpellet period. When a tone followed the tenth response in the chained component and initiated the second (and longer) link in the chain, licking tended to occur shortly after the second link began.

Flory and O'Boyle (1972) and Gilbert (1974) both found that licking would occur at times other than after the pellet when the water tube was not available immediately following pellet delivery. The present study extends these findings by showing that drinking is not restricted to the postpellet period even when the drinking tube is freely available. These findings also support research with second-order schedules and with reinforcement omission procedures in which drinking followed brief-stimulus changes (Corfield-Sumner et al., 1977; Porter & Kenshalo, 1974; Rosenblith, 1970).

Table 2

The mean number and range of the licks per episode following the pellet before initiation of the 100 responses, before initiation of the FR 10 or following responses on the component requiring 100 responses.

Subject	Condition	100-response component		10-response component
		Postpellet (pre-FR 100 or chain)	Postresponse	Postpellet (pre-FR 10)
R-1	Mix	221 (221-221)	149.8 (144.4-168.6)	— —
	Mult	141.6 (112.1-186.5)	112.8 (74.2-168.2)	— —
	Mix	88.2 (33.0-142)	97.9 (91.2-111.6)	— —
	Mult	101.9 (86.1-142.5)	63.1 (45.2-77.6)	— —
R-2	Mix	— —	43.7 (33.6-57.8)	— —
	Mult	65.9 (51.7-87.1)	65.83 (41.7-80.0)	— —
	Mix	— —	88.2 (69.6-112.8)	— —
	Mult	66.1 (48.8-94.2)	64.45 (25-130)	— —
R-3	Mix	97.4 (81.0-111.3)	24.2 (11.8-46.7)	98.3 (80.0-113.3)
	Mult	124.1 (107.1-133.3)	12.8 (4.3-25.5)	103.7 (85.6-111.8)
	Mix	98.4 (58.5-136.2)	17.2 (9.0-30.2)	96.2 (73.7-126.5)
	Mult	71.4 (94.9-146.4)	1.0 (1.0-1.0)	108.3 (92.9-139.0)
R-4	Mix	45.2 (40.4-52.6)	37.9 (33.4-66.6)	44.0 (39.8-48.6)
	Mult	49.5 (42.7-58.0)	23.4 (1.0-49.0)	54.2 (43.0-63.5)
	Mix	53.1 (41.4-64.3)	10.7 (1.5-14.7)	53.1 (46.0-64.2)
	Mult	46.6 (38.9-57.3)	42.9 (1-61.3)	46.3 (23.5-51.7)

Rosenblith (1970) accounted for the licking following the brief stimuli in second-order schedules by describing the brief stimulus as a Pavlovian conditioned stimulus (CS) which elicited licking as a result of its pairing with the food pellet. Yet several investigators have failed to find drinking following stimuli paired with food (Iverson, 1977; McCoy & Christian, 1976; Allen & Porter, 1977; Porter, Arazie, Holbrook, Cheek, & Allen, 1975). In those instances in which their subjects did drink following the brief stimulus, Allen and Porter (1977) characterized this drinking as

“resumptive postpellet drinking” or as “low-rate terminal behavior.”

Because they reduced or eliminated postpellet licking, the present procedures offer an advantage over brief-stimulus procedures. In the present study, two of the rats did not lick significantly following the food pellet on the *mix* FR 10 *chain* FR 10 FR 90 schedule even though they did lick at a high rate after the onset of the tone. Therefore, this licking is not a resumption of licking after the food pellet, nor is it low-rate terminal behavior. Moreover, onset of the tone was not paired with



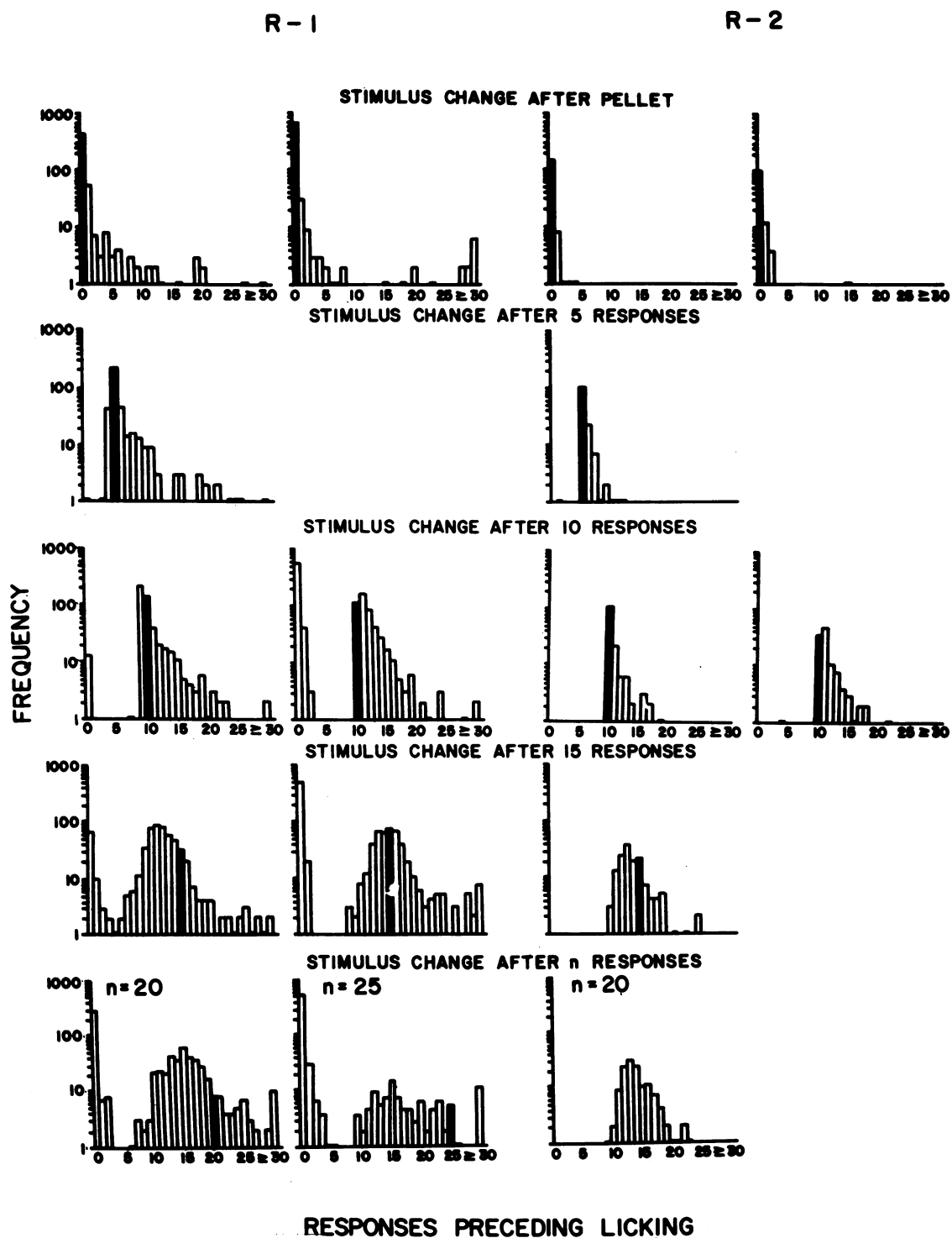


Fig. 3. Frequency of licking episodes at each location in the component requiring 100 responses for R-1 and R-2 in each condition in Phase 2. The first exposure to each condition is presented on the left for each subject and the second exposure on the right. The point at which the stimulus change occurred is marked by a darkened bar. Note the log scale on the y-axis.

the food pellet during the *mix* FR 10 *chain* FR 10 FR 90 schedule; the tone came on 10 responses after the last pellet and 90 responses before the next pellet. Yet licking still followed the tone. Corfield-Sumner *et al.* (1977) also found that drinking would follow a brief stimulus that was not paired with food in a second-order schedule. These findings suggest that drinking following the tone in the present study did not result from the pairing of the tone with a food pellet.

It is possible that the tone was not an arbitrary stimulus but in fact elicited drinking without any prior conditioning. Several aspects of the data argue against this. First, on the multiple schedule, the tone accompanied the FR 10 rather than the FR 100 component. Two of the rats never drank during the FR 10 component following the presentation of the tone. Second, during the 2nd phase of the experiment when the tone followed the 20th or the 25th response in the chain, most of the licking occurred before the onset of the tone instead of following it. Moreover, when the simple FR 10 component of the mixed schedule was eliminated for rat R-2 (*i.e.*, the schedule was *chain* FR 10 FR 90), licking followed pellet delivery rather than tone onset. This evidence suggests that the tone *per se* did not produce drinking and that the tone was an "arbitrary" stimulus.

It is interesting to note that rats R-1 and R-2, which drank following tone onset rather than postpellet in the mixed schedule, never drank during FR 10 while rats R-3 and R-4 drank during FR 10 and engaged in considerable postpellet licking. R-3 and R-4 also drank greater volumes of water per day in each schedule than they did during baseline while polydipsia did not develop for either R-1 or R-2 during the first mixed schedule. This relation between the delayed onset of polydipsia and the control of licking by tone onset may hold the key to understanding the variables which control the temporal placement of polydipsic licking and should be investigated further in the future.

Stein (1964) suggested that polydipsic drinking was produced by ingestion of the dry pellet. One of the principal sources of evidence for this suggestion has been the postpellet location of polydipsic drinking. However, in the present study, drinking was strictly postpellet only on the multiple schedule. In the mixed

schedule conditions, licking followed the onset of a tone. Presentation of this tone should not have the same effects on thirst as the ingestion of a dry pellet.

These data are consistent with the suggestion that schedule-induced licking is an interim or adjunctive behavior controlled by changes in the probability of food (Falk, 1969; Staddon & Simmelhag, 1971). During time periods in reinforcement schedules when the probability of food is low, schedule-induced licking is likely to occur. In the multiple FR 10 FR 100 schedule in the present study, the time when the probability of food is lowest is following pellet delivery and before the first response on the FR 100 component. To a lesser extent, the probability of food delivery is also low before the first response on the FR 10 component. All four rats drank predominantly before the first response on the FR 100 schedule during this condition, and two rats also drank before the first response on the FR 10 schedule.

On the *mix* FR 10 *chain* FR 10 FR 90 schedule, the probability of food was lowest early during the component requiring 100 responses. However, the stimulus conditions following pellet delivery were identical whether the next component required 10 or 100 responses. On the FR 10, 10 responses produced a food pellet. The first 10 responses in the chain produced only the tone, and 90 additional responses were needed to produce a pellet. Since there was a probability of .25 that food would be presented following the 10th response, the time when the probability of food was at a minimum was just after the onset of the tone. And onset of the tone tended to be followed by licking although two of the subjects also drank after pellets.

A similar analysis applied to the second phase of the experiment. The tone signaled a low probability of reinforcement when it followed 5 or 10 responses in the chain. However, when the tone was delayed until after 15, 20, or 25 responses, information that the component required 100 rather than 10 responses was available when the 10th response did not produce food. This information provided by the tone was therefore redundant, and drinking was not necessarily correlated with tone onset under these conditions.

The results suggest that schedule-induced licking is controlled by stimuli which signal

a period when the probability of food delivery is low. This seems true whether the stimulus serving this function is a tone, a food pellet, or the completion of 10 to 15 responses. However, one line of evidence suggests that the tone and the food pellet are not completely substitutable; more licks occurred per episode when that episode followed a pellet than in episodes following a response. This suggests that the control exerted by the pellet was not based totally on the discriminative properties of the food. This is consistent with Stein's (1964) suggestion that ingesting dry food induces thirst. However, the enhancement of licks by the pellet was restricted to the postpellet period. The number of licks was lower if even a single response separated a pellet from a drink. The principal control over licking was exerted by a stimulus which signaled a low probability of food. Ingesting food had only a small additional effect. Whether this additional effect resulted from a "dry mouth" or from other factors remains to be investigated.

## REFERENCES

- Alferink, L. A., & Crossman, E. K. Mixed fixed-ratio schedules: Priming and the pre-ratio pause. *The Psychological Record*, 1975, 25, 123-130.
- Alferink, L. A., & Crossman, E. K. Mixed fixed-ratio schedules II: The effect of a stimulus change on primes in the large ratio. *Revista Mexicana de Analisis de la Conducta*, 1976, 2, 22-32.
- Allen, J. D., & Porter, J. H. Sources of control over schedule-induced drinking produced by second-order schedules of reinforcement. *Physiology and Behavior*, 1977, 18, 853-863.
- Corfield-Sumner, P. K., Blackman, D. E., & Stainer, G. Polydipsia induced in rats by second-order schedules of reinforcement. *Journal of the Experimental Analysis of Behavior*, 1977, 27, 265-273.
- Falk, J. L. Conditions producing psychogenic polydipsia in animals. *Annals of the New York Academy of Sciences*, 1969, 157, 569-593.
- Falk, J. L. Production of polydipsia in normal rats by an intermittent food schedule. *Science*, 1961, 133, 195-196.
- Falk, J. L. A theoretical review: The nature and determinants of adjunctive behavior. *Physiology and Behavior*, 1971, 6, 577-578.
- Ferster, C. B., & Skinner, B. F. *Schedules of reinforcement*. New York: Appleton-Century-Crofts, 1957.
- Flory, R. K., & O'Boyle, M. K. The effect of limited water availability on schedule-induced polydipsia. *Physiology and Behavior*, 1972, 8, 147-149.
- Gilbert, R. M. Ubiquity of schedule-induced polydipsia. *Journal of the Experimental Analysis of Behavior*, 1974, 21, 277-284.
- Iverson, I. H. Reinforcement omission and schedule-induced drinking in a response-independent schedule in rats. *Physiology and Behavior*, 1977, 18, 535-537.
- Keehn, J. D., & Colotla, V. A. Prediction and control of schedule-induced drink durations. *Psychonomic Science*, 1970, 21, 147-148.
- Keehn, J. D., & Colotla, V. A. Stimulus and subject control of schedule-induced drinking. *Journal of the Experimental Analysis of Behavior*, 1971, 16, 257-262.
- McCoy, J. F., & Christian, W. P. Schedule-induced drinking and reinforcement omission. *Physiology and Behavior*, 1976, 17, 537-539.
- Millenson, J. R., Allen, R. B., & Pinker, S. Adjunctive drinking during variable and random-interval food reinforcement schedules. *Animal Learning and Behavior*, 1977, 5, 285-290.
- Porter, J. H., Arazie, R., Holbrook, J. W., Cheek, M. S., & Allen, J. D. Effects of variable and fixed second-order schedules on schedule-induced polydipsia in the rat. *Physiology and Behavior*, 1975, 14, 143-149.
- Porter, J. H., & Kenshalo, D. R. Schedule-induced drinking following omission of reinforcement in the rhesus monkey. *Physiology and Behavior*, 1974, 12, 1075-1077.
- Rosenblith, J. Z. Polydipsia induced in the rat by a second-order schedule. *Journal of the Experimental Analysis of Behavior*, 1970, 14, 139-144.
- Segal, E. F., & Holloway, S. M. Timing behavior in rats with water drinking as a mediator. *Science*, 1963, 110, 888-889.
- Smith, J. B., & Clark, F. C. Intercurrent and reinforced behavior under multiple spaced-responding schedules. *Journal of the Experimental Analysis of Behavior*, 1974, 21, 445-454.
- Staddon, J. E. R. Schedule-induced behavior. In W. K. Honig & J. E. R. Staddon (Eds.), *Handbook of operant behavior*. Englewood Cliffs, N.J.: Prentice-Hall, 1977.
- Staddon, J. E. R., & Simmelhag, V. L. The "superstition" experiment: A reexamination of its implications for the principles of adaptive behavior. *Psychological Review*, 1971, 78, 3-43.
- Stein, L. Excessive drinking in the rat: Superstition or thirst? *Journal of Comparative and Physiological Psychology*, 1964, 58, 237-242.
- Stone, W., Lyon, D. O., & Anger, D. Suppression of postpellet licking by a Pavlovian S+. *Bulletin of the Psychonomic Society*, 1978, 12, 117-119.

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